CUSTOMER NO. 46850 ***PATENT***

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Re: Attorney Docket No. Liu 25-18-17-7

In re application of: Xiang Liu, Lothar Benedikt Erhard Josef Moeller, Xing Wei, and Chongjin Xie

Serial No.:	10/730,413	Group Art Unit:	2613
Filed:	12/08/2003	Examiner:	Pascal, Leslie C.
Matter No.:	990.0506	Phone No.:	571-272-3032

For: Duobinary Receiver

DECLARATION UNDER 37 CFR 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

1. I am an applicant of the above-identified patent application ("present application") and an inventor of the subject matter described and claimed therein.

2. I have been working at Lucent Technologies and then Alcatel-Lucent for over ten years, where I am a Member of Technical Staff. Over the years, I have worked on various design aspects of fiberoptic communications systems.

3. The Optical Fiber Communication Conference and Exposition (OFC) is the largest and most highly regarded annual event worldwide in the optical-communications community (see also Exhibit A).

4. OFC postdeadline papers are widely regarded as showing most important and innovative R&D results in the field of fiber optics in each particular year. A jury of about 10-15 top experts from the industry and academia selects a very limited number of postdeadline papers to be presented. Postdeadline-paper sessions are among the best attended at the OFC and most widely quoted (see also Exhibit B).

5. The subject matter of the present application was described in a submission to the OFC held in February of 2004, which submission was accepted and presented thereat as a postdeadline paper entitled "10 Gb/s Duobinary Receiver with a Record Sensitivity of 88 Photons per Bit" (see Exhibit C).

6. The above-indicated submission to the OFC was accepted as a postdeadline paper because said submission demonstrated **unexpected, record-setting** results. In particular, a record OSNR of about 10.8 dB @BER=10^{-3} had been achieved for optical duobinary signals that were processed at the receiver using a sampling-window width of less than about 25% of the bit length (see the footnote on the fourth page of Exhibit C).

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

4/7/09

Date

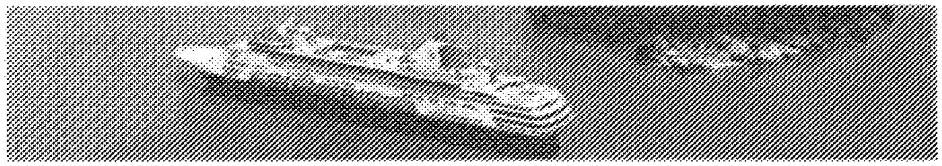
Lothar Benedikt Erhard Josef Moeller

Exhibit A

Optical Fiber Communication Conference & Exposition (OFC) 2004

Search

AllConferences.com > Science >



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Paleontology
Physics
Policy
Psychology
Research
Technology
Space
Vibrations
Wireless

Event	Optical Fiber Communication Conference & Exposition (OFC) 2004						
Begins	February 22, 2004	Ends	February 27, 2004	Papers		Ab.	OFC 2004
Country	USA	State	California	City	Los Angeles	Email	mschip@ofcconference.org
Category	Science	Category 2	-	Category 3	-	Exhibits	Y
Organization				Contact			
URL	http://www.ofcconference.org						
Venue	Los Angeles Convention Center						
Description	The Optical Fiber Communication Conference and Expositon (OFC) is the largest and most highly regarded event in the industry. No other conference draws nearly the audience of buyers, business leaders, executive managers and developers. That is because only OFC provides both a high-powered, commerce-driven exhibition with leading edge, peer-reviewed educational programming. Plenary Session ? Each year, OFC begins with a powerful Plenary Session that addresses the topics, trends and issues at the firefront of the field.						
Additional Information							

Exhibit B

IEEE COMSOC TCPC
IEEE COMMUNICATIONS SOCIETY
TECHNICAL COMMITTEE ON PERSONAL COMMUNICATIONS

Minutes of the meeting held at WCNC'99
Hyatt Regency New Orleans, Tuesday 23 September 1999 (2:00 4:00 pm)

Minutes
(Minutes taken by Khaled Ben Letaief)

Chair: Zygmunt J. Haas

Present:

Zygmunt Haas, Khaled Ben Letaief, Moe Win, Giovanni Corazza, Upkar Varshney, Hamid Aghavami, Demitros Kazakos, Kainam Thomas Wong, Greg Pollini, Jerry Gibson, Dhawal B. Moghe, Mark Haas, Tom Stevenson, Yuguang Fang.

1. The meeting started at 2:10 pm.

2. Minutes of the TCPC meeting held in ICC'99, Vancouver were approved.

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[...]

****

8. Conferences and Meetings Reports

[...]

5. They discussed a proposal from the Meetings and Conferences Committee for "Post Deadline Papers."

The "post deadline" paper have been used effectively at the OFC conference for approximately a decade to attract last minute submissions on hot topics that might otherwise not be considered. Nim Cheung said that the "post deadline" paper sessions are among the best attended and most widely quoted at OFC.

The process requires the Technical Program Committee to select papers the night before the opening day of the conference based one 3-4 page summaries submitted by potential speakers. At OFC only a very small percentage of papers are typically selected. "Post deadline" paper sessions are typically held from 4-6 in the evening. Unlike poster sessions, which often consist of papers that are not strong enough to make the first cut, the post deadline paper submissions tend to be of a high quality and are often submitted by top experts.

[...]

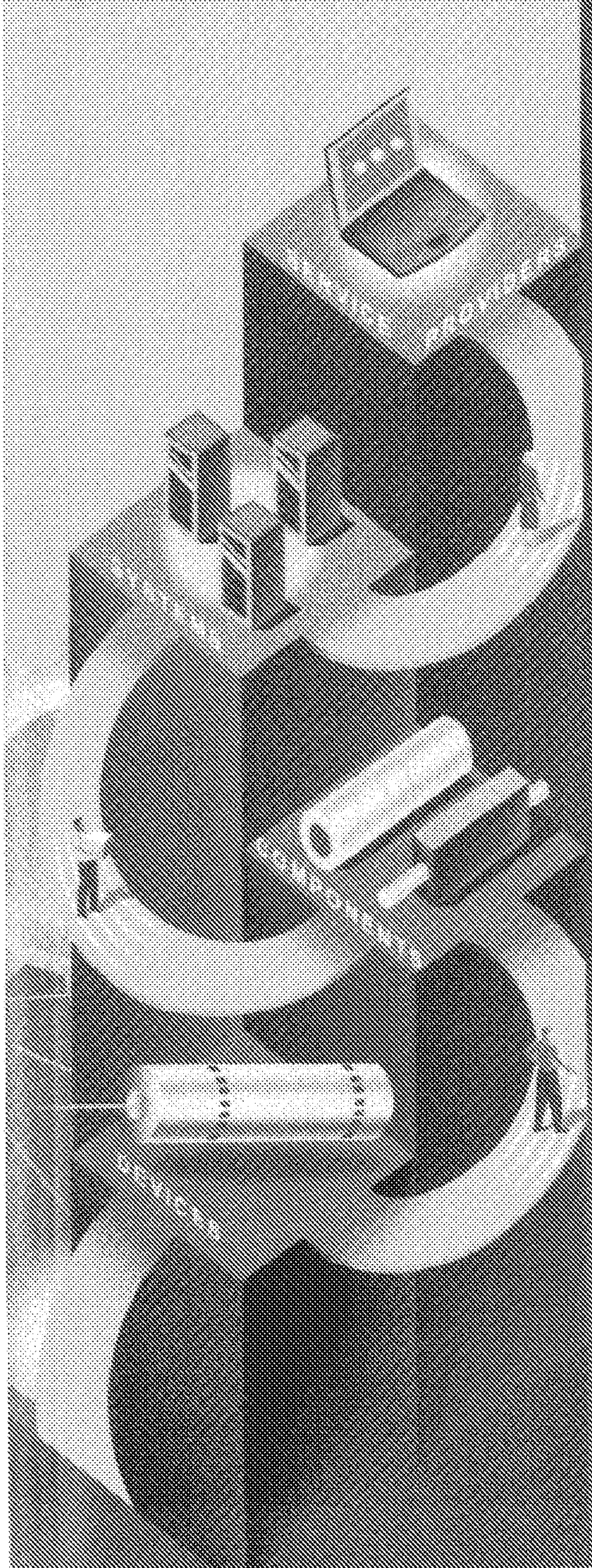
There was no other business. The meeting was adjourned at 3:45 p.m.

Exhibit C

OFC:04

Optical Fiber Communication
Conference & Exposition

The Leading International Optical Communications Event Since 1975!



Postdeadline Papers

Technical Conference: February 22-27, 2004
Exposition: February 24-26, 2004

Los Angeles Convention Center
Los Angeles, California, USA

Sponsored by

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www.ofcconference.org

Exhibit C (continued)

PDP25 5:30 p.m.
First demonstration of air-silica Bragg fiber, *G. Vienne[1], Y. Xu[2], C. Jakobsen[1], H. J. Deyerl[3], T. P. Hansen[1], B. H. Larsen[1], J. B. Jensen[1], T. Sørensen[3], M. Terrel[2], Y. Huang[2], R. Lee[2], N. A. Mortensen[1], J. Broeng[1], H. Simonsen[1], A. Bjarklev[3], A. Yariv[2]; [1]Crystal Fibre A/S, Denmark, [2]Caltech, USA, [3]COM Ctr., Technical Univ. of Denmark, Denmark, [4]NKT Res. & Innovation, Denmark. We present experimental and theoretical results on air-silica Bragg fibers. The TE_{01} mode is observed for the first time to our knowledge in Bragg fibers. We could transmit light by bandgap guiding over 50 m.*

PDP26 5:45 p.m.
Bismuth-based optical fiber with nonlinear coefficient of 1360 $W^{-1}km^{-1}$, *Naoki Sugimoto[1], Tatsuo Nagashima[1], Tomoharu Hasegawa[1], S. Ohara[1], Kenji Taira[2], Kazuro Kikuchi[2]; [1]Asahi Glass Co., Japan, [2]Univ. of Tokyo, Japan. We develop a conventional step-index type highly nonlinear bismuth oxide-based glass fiber. This fiber exhibits high nonlinearity (γ=1360 $W^{-1}km^{-1}$) because of the high nonlinearity of the glass material and the small effective core area.*

PDP27 6:00 p.m.
UV processing of highly nonlinear fibers for enhanced supercontinuum generation, *Paul Westbrook, Jeff Nicholson, Ken Feder, Andrew Yablon; OFS Labs., USA. We demonstrate that UV exposure of highly nonlinear germanosilicate fibers can significantly enhance the IR supercontinuum generation in these fibers, extending it from 1950nm to 2050nm when pumped by 30 fs pulses at 1550nm.*

Room: 315A
Session: Postdeadline IV
4:30 p.m. – 6:45 p.m.

Subcommittee G: Subsystems, Network Elements, and Analog Systems
Benny Mikkelsen, Mintera Corp., USA, Presider

PDP28 4:30 p.m.
Compact 160 Gb/s add-drop multiplexing with a 40 Gb/s base-rate, *Hsu-Feng Chou, John E. Bowers, Daniel J. Blumenthal; Univ. of California at Santa Barbara, USA. We report on the first 40 Gb/s-based OTDM add-drop multiplexing at 160 Gb/s using electrically driven electroabsorption modulators. Error-free operation for all channels is obtained with an average power penalty of 1 dB.*

PDP29 4:45 p.m.
Four user, 2.5 Gb/s, spectrally coded O-CDMA system demonstration using low power nonlinear processing, *Zhi Jiang[1], Dongsun Seo[1], Shang-Da Yang[1], Daniel E. Leaird[1], Andrew M. Weiner[1], Rostislav V. Roussev[2], Carsten Langrock[2], Martin M. Fejer[2]; [1]Purdue Univ., USA, [2]Stanford Univ., USA. We demonstrate for the first time 2.5 Gb/s four user O-CDMA operation at ≤ 10^{-11} BER utilizing programmable spectral phase encoding, an ultrasensitive (~0.4 pJ/bit) PPLN-waveguide nonlinear waveform discriminator and 10G Ethernet receiver.*

PDP30 5:00 p.m.
10 Gb/s Synchronous receiver with a record sensitivity of 58 photons per bit, *[illegible] Moeller, Chongjin Xie, Roland Ryf, Xiang Liu, Xing Wei; Bell Labs, Lucent Technologies, USA. We demonstrate a novel receiver concept for duobinary signals that allows for data recovery with a sensitivity of -39 [illegible] (58 Photons/bit, BER=1E-9). [illegible] together with maximum likelihood sampling phase estimation results in superior back-to-back performance.*

PDP31 5:15 p.m.
Adaptive PMD compensator in 160Gb/s DPSK transmission over installed fiber, *Sven Kieckbusch[1], Sebastian Ferber[2], Harald Rosenfeldt[3], Reinhold Ludwig[2], Christof Boerner[2], Armin Ehrhardt[4], Ernst Brinkmeyer[1], Hans-Georg Weber[2]; [1]Technische Univ. Hamburg-Harburg, Germany, [2]Fraunhofer Inst. for Telecommunications, Heinrich-Hertz-Institut, Germany, [3]Adaptif Photonics GmbH, Germany, [4]T-Systems, Germany. We report on a magneto- and electro-optically tuned dynamic PMD compensator that enabled error-free single-channel 160Gb/s RZ-DPSK transmission over a 116km SMF link (PMD≈0.3T_{bit}). Polarization scrambling and DOP measurements were utilized to automatically adapt the compensator.*

PDP32 5:30 p.m.
Compensation of intra-channel nonlinearities in 40 Gb/s pseudo-linear systems using optical phase conjugation, *Arel Chowdhury, Gregory Raybon, Rene-Jean Essiambre, Jeffrey Sinsky, Andrew Adamiecki, Juerg Leuthold, Christopher R. Doerr, Sethumadhavan Chandrasekhar; Bell Labs, USA. We compensate intra-channel nonlinearities in an RZ-DPSK 40Gb/s 32×100km system using a $LiNbO_3$ conjugator and achieve 2 decades of improvement in BER. Transmission limited to 3,200km at a BER=3×10^{-4} is extended to 6,400km with phase conjugation.*

PDP33 5:45 p.m.
Direct measurement of constellation diagrams of optical sources, *Christophe Dorrer, Juerg Leuthold, Christopher R. Doerr; Bell Labs, Lucent Technologies, USA. We present the first temporal diagnostic that measures statistical information on both the intensity and phase of data-encoded channels. Experimental characterization of differential-phase shift keyed signals at 10 Gb/s and 40 Gb/s is presented.*

Subcommittee F: Digital Transmission Systems
Alan Gnauck, Lucent Technologies, Bell Labs., USA, Presider

PDP34 5:30 p.m.
RZ-DPSK field trial over 13,100 km of installed non slope-matched submarine fibers, *Jin-Xing Cai, Dmitri Foursa, Li Liu, Carl Davidson, Yi Cai, Will Patterson, Alan Lucero, Bamdad Bakhshi, Georg Mohs, Pat Corbett, Vishal Gupta, William Anderson, Michael Vaa, George Domagala, Matt Mazurczyk, Haifeng Li, Morten Nissov, Alexei Pilipetskii, Neal Bergano; Tyco Telecommunications, USA. We successfully conducted a 96×10Gb/s RZ-DPSK field trial over an installed 13,100km optical undersea path with more than 3dB FEC margin, including channels with >13,000ps/nm dispersion. The performance was further improved 1.2dB by adding pre-chirp.*

PDP35 5:45 p.m.
6 x 42.7 Gb/s transmission over ten 200 km EDFA-amplified SSMF spans using polarization-alternating RZ-DPSK, *A. H. Gnauck[1], J. Leuthold[1], C. Xie[1], I. Kang[1], S. Chandrasekhar[1], P. Bernasconi[1], C. Doerr[1], L. Buhl[1], J. D. Bull[2], N. A. F. Jaeger[2], H. Kato[2], A. Guerin[2]; [1]Lucent Technologies, Bell Labs, USA, [2]JDS Photonics, Canada. We demonstrate the use of polarization alternation to dramatically improve performance in 42.7-Gb/s WDM transmission. Six channels are transmitted through ten 200-km (39-dB loss) standard single-mode fiber spans with amplification provided solely by erbium-doped fiber amplifiers.*

PDP36 6:00 p.m.
WDM transmission at 6 Tbit/s capacity over transatlantic distance, using 42.7Gb/s Differential Phase-Shift Keying without pulse carver, *Gabriel Charlet[1], Bruno Corbel[1], Jose Lazaro[1], Axel Klekamp[2], Roman Dischler[2], Patrice Tran[1], Wilfried Idler[2], Haik Mardoyan[1], Agnieszka Konczykowska[3], Filipe Jorge[3], Sebastien Bigo[1]; [1]Alcatel R&I, France, [2]Alcatel R&I, Germany, [3]Opto+, France. We report the transmission of a record 6Tbit/s capacity over 6,120km, involving channels modulated at 42.7Gb/s bit-rate with Differential Phase-Shift Keying (DPSK). The performance is found similar to DPSK with subsequent pulse carving, namely RZ-DPSK.*

PDP37 6:15 p.m.
42 × 42.7 Gb/s RZ-DPSK transmission over a 4820 km long NZDSF deployed line using C-band-only EDFAs, *Loïc Becouarn[1], Ghislaine Vareille[1], Sebastien Dupont[1], Philippe Plantady[1], Jean-François Marcerou[1], Axel Klekamp[2], Roman Dischler[2], Wilfried Idler[2], Gabriel Charlet[1]; [1]Alcatel, France, [2]Alcatel, Germany. The transmission of 42 RZ-DPSK channels at 42.7Gb/s is demonstrated over 4820 km of NZDSF deployed line with more than 3dB margin. A performance comparison with the same capacity using 168×10Gb/s DPSK is demonstrated.*

PDP38 6:30 p.m.
1.14 b/s/Hz spectrally-efficient 50 x 85.4 Gb/s transmission over 300 km using copolarized CS-RZ DQPSK signals, *Noboru Yoshikane, Itsuro Morita; KDDI R&D Labs, Inc., Japan. 1.14 b/s/Hz spectrally-efficient 50 x 85.4 Gb/s transmission over 300 km of NZ-DSF has been successfully demonstrated with copolarized CS-RZ DQPSK signals. 42.7 Gsymbol/s-based 4Tb/s DQPSK transmission has been achieved without polarization multiplexing.*

Exhibit C (continued)

PDP30

10 Gb/s Duobinary Receiver with a Record Sensitivity of 88 Photons per Bit

Lothar Möller, Chongjin Xie, Roland Ryf, Xiang Liu, Xing Wei
Bell Labs, Lucent Technologies, 791 Holmdel-Keyport RD, NJ 07733, USA, lmoeller@lucent.com

Abstract: We demonstrate a novel receiver concept for duobinary signals that allows for data recovery with a sensitivity of -39.5dBm (88 Photons/bit, BER=1.10^{-9}, 2^{31}-1 PRBS). Oversampling together with maximum likelihood sampling phase estimation results in superior back-to-back performance without lowering the large chromatic dispersion tolerance of duobinary signaling.

OCIS codes: (060.2330) Fiber optics communications, (060.4080) Modulation

1. Introduction

Optical duobinary signaling provides superior protection against chromatic dispersion (CD) impairments when compared to other modulation techniques, making it an interesting candidate for network applications since costs for CD compensation can be reduced [i-iii].
However, although the duobinary transmitter technology, similar in complexity to that of its rival, the NRZ signal[iv], has been available for a long time, it has not yet been widely used in commercial products. One reason for this is its weaker back-to-back (b-b) performance. In contrast to published simulations results, predicting that duobinary requires a smaller optical signal to noise ratio (OSNR) than NRZ at a given BER, so far all reported experimental data show the opposite. While compared with NRZ the maximum uncompensated transmission length of duobinary under the assumption of a 2dB CD penalty can be three times larger, in a b-b performance measurement, it is typically a few dB worse in required OSNR. This fact is of great practical significance since the next generation of TXs must advantageously run on both CD compensated (equivalent to b-b operation) and CD uncompensated links.
Several pulse-shaping techniques, applied on the TX side, have been proposed to overcome the b-b performance problem[v,vi]. However, all these techniques seem to improve the b-b performance at the expense of some amount of CD tolerance since they rely on pulse width reduction techniques.
Here we show that timing jitter of the transmitter and the sampling window width of the RX are key design quantities of high sensitivity duobinary transceivers. Based on these insights we developed a novel RX concept utilizing maximum likelihood optimal sampling phase estimation (MLPE) that allows duobinary reception with a record sensitivity, which is very close to the best reported one for 10Gb/s NRZ[vii] without losing any CD tolerance.

2. Receiver sensitivity enhancement by sampling window width reduction (Quasi Dirac Sampling, QDS)

A duobinary signal with large CD tolerance can be generated by low-pass filtering (LPF) the electrical driver signal for the Mach-Zehnder modulator. Fig 1a shows a simulated LPF duobinary b-b eye diagram, which has a distinct intensity "ripple" on the zero rail and a crossing point higher than that of NRZ[iii]. The ripple on the zero rail and the narrow space valley are known to be associated with the good CD tolerance of LPF duobinary signals, but they lead to poor b-b performance of duobinary compared to NRZ. Conventional data decision circuits integrate the signal power over a fraction of the bit length (sampling window) before comparing the integrated signal with a threshold voltage. The undesired optical power near the center of a zero bit inevitably would contribute to the integral and therefore the decision threshold has to be set higher than that of a NRZ signal to minimize the BER. More precisely, if the sampling window height is located too close to the space level (position A, fig 1a), the data decision can be corrupted by integrating too much of the energy

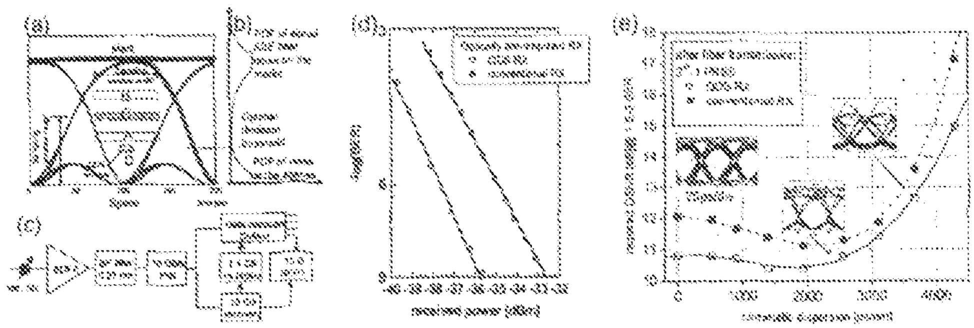

Fig 1: (a) Sketched positions of different sampling windows, (b) noise distributions of the ONES and ZERO and the opt. decision threshold. (c) Set-up of the QDS RX, (d) BER curves for the QDS RX and a conv. RX, (e) CD tolerances of the QDS RX and a conv. RX.

Exhibit C (continued)

stemming from adjacent pulses (ISI). On the other hand, if the window is located too close to the mark level (position B, fig.1a), the signal ASE beat noise that dominates in an optical pre-amplified RX and is larger on marks, would impair the decision. In other words, the selection of the decision threshold (position C, Fig.1a) of a conventional RX is a compromise between suffering degradation from ISI and noise and it can not be set to a level that would be the optimum choice regarding the noise distribution functions (Fig.1b) alone in an ISI free signal. Less ISI energy integration and noise collection becomes possible simply by shortening the sampling window width (Quasi Dirac Sampling, QDS) and moving the window position deeper in the space valley (position D, Fig.1a).

Experimental setup and results

Conventional data decision consists of cascaded master and slave flip-flops that are triggered on the rising edge of the clock tone. To emulate a reduced sampling window width we drive the flip-flops of our customized GaAs ASIC with a clock frequency that is four times higher than the data rate. This yields a window width of approx. 10ps. De-multiplexing of the 40Gb/s pulse stream recovers the original 10 Gb/s data pattern. The overall RX architecture is shown in Fig.1c. Note, the O/E converter (PIN) including the transimpedance amplifier has a bandwidth of approx. equal 80% (~8GHz) the data rate. Thus the noise characteristics of the RX appear to be no worse than those of a conventional RX as one might think due to the higher bandwidth of the data decision circuit.

To demonstrate the performance gain of our RX, we carried out all measurements twice under the same conditions with the exception of using a conventional 10 Gb/s limiting amplifier (Nortel GB 79), known for its high sensitivity, as a data decision circuit in this case. The commercially available duobinary TX is based on LP filtering with 2.5 GHz bandwidth and generates a pp-jitter of less than 25ps.

Fig.1d shows the BER curves for both RXs obtained when an optical pre-amplifier was used and indicates a QDS RX gain of ~3 dB at a BER= 1. 10^{-9} (Sensitivity ~-36dBm[1]). Since the next generation of transmission systems are expected to run with forward error correction coding (FEC), we measured the CD tolerance of the RXs at a BER = 1. 10^{-3}, which is close to the threshold of enhanced FEC with 7% overhead. However, the data rate of the 2^{31}-1 PRBS was kept at SONET rate in order to make the results comparable to previously published reports, which mainly focus on 10Gb/s experiments. The b-b performance of our RX is ~1.4 dB improved by QDS resulting in ~10.8dB required OSNR[1] @ BER=1. 10^{-3} (measured at 0.1nm OSA resolution). Note, the b-b performance is less than 0.5dB worse[2] compared to that at the optimal amount of CD (at ~2000 ps/nm). For a 2 dB OSNR penalty, we measured with the QDS RX tolerable CD amounts of ~ 3735 ps/nm.

3. Oversampling together with logic signal processing for additional RX sensitivity enhancement

Further RX sensitivity improvement can be achieved when timing jitter mitigation techniques are applied. Fig.2a shows the simulated eye closures due to jitter for duobinary and regular NRZ. Obviously jitter requires rising the threshold in the case of duobinary to eliminate ISI effects in the decision process, which shifts the threshold away from the optimal value regarding the noise distributions. For the case of NRZ, the same amount of jitter does not require a threshold change due to

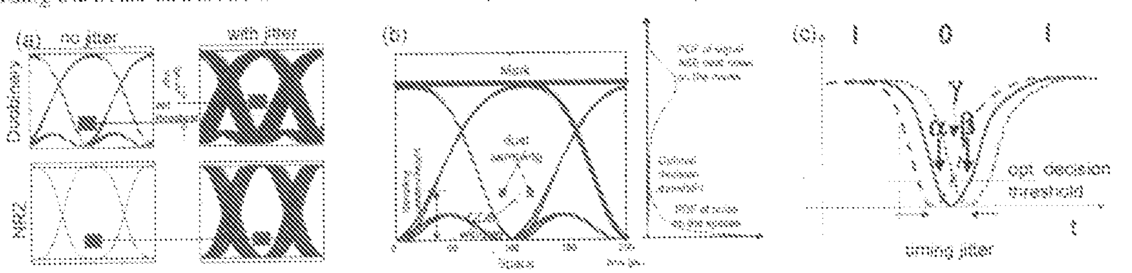

Fig.2: (a) Threshold lifting due to jitter impairments for duobinary and NRZ, (b) Sketched sampling window positions for dual sampling, (c) 1,0,1 pattern transitions with jitter relative to the sampling points of dual sampling (α,β) and mono sampling (γ)

the wide zero valley. For jitter mitigation purpose we extended the QDS RX scheme by establishing more than one sampling point with a short window width per bit slot (see in Fig.2b the case of dual sampling). Fig.2c shows the '1,0,1'-pattern transitions, most susceptible to ISI, after the O/E conversion of the signal when jitter is present. We assume, for the sake of simplicity, that the timing jitter between the adjacent ONE pulses is strongly correlated. Then by performing dual sampling with sampling points α and β and combining the obtained data samples through a logical AND operation, a wrong decision on a ZERO made by i.e. α can still be overturned by the correct decision of β. A similar argument holds for the case when ASE noise corrupts the decision process. It is expected to be unlikely that both pulses are distorted and negatively influence both α and β since the noise processes in the two neighboring bit slots are only weakly correlated. The impact of signal-ASE beat noise generated within the center of the ZERO bit slot (possibly caused by insufficient extinction ratio and the distinct ZERO ripple of duobinary) could be slightly mitigated by oversampling too. In summary, every symbol is sampled more than one time per bit slot. In the case that one sampling result is ZERO, the possibility of different results on neighboring sampling points is eliminated. Since it is more likely that a ZERO than a ONE is corrupted, our procedure maximizes the likelihood that the optimal sampling phase for a ZERO was selected (Maximum

[1] This is the best value reported for 10 Gb/s duobinary in the literature so far. Previously published sensitivities are [illegible]